Renewable Energy Systems

Module 9

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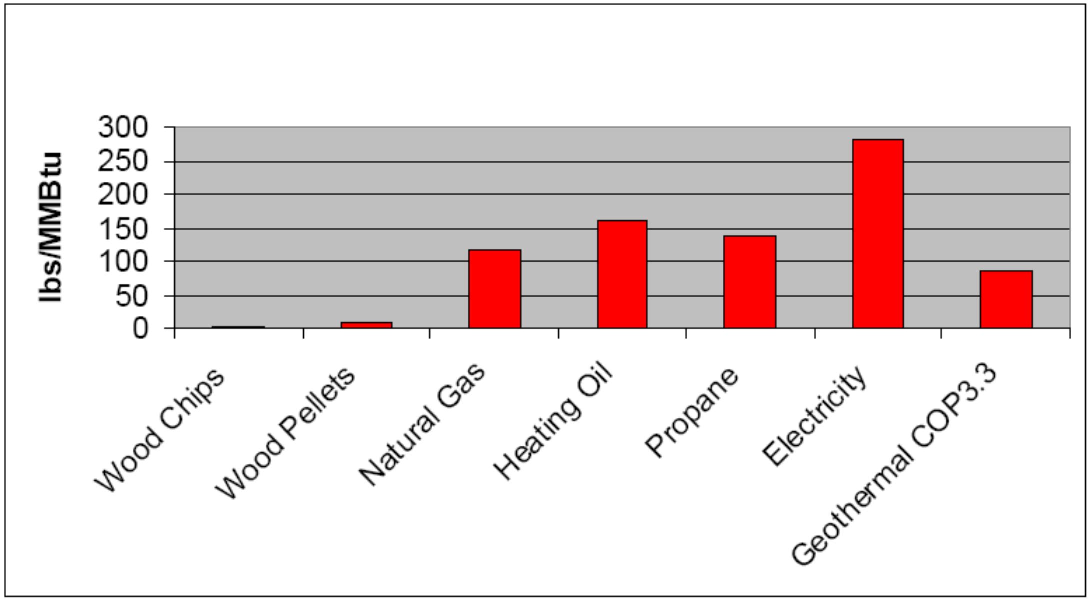
Introduction

A renewable energy is an energy source which can be replenished naturally and indefinitely and thus is not going to run out. The benefits of such energy sources are obvious in terms of supply – but another important benefit is that renewable energies are much better for the environment than conventional fossil fuels such as oil, gas and coal. This is because burning fossil fuels adds greenhouse gases, which have been 'locked up' within the Earth, back into the atmosphere. This is a major cause of the phenomenon known as '**Climate Change**'.

Renewable heating sources (solar thermal, geothermal, biomass) have a huge potential for growth and can replace substantial amounts of fossil fuels and electricity currently used for heating purposes. **Solar thermal, geothermal energy and biomass** offer heating at virtually zero CO^2 emissions.

Introduction Cont.

CO^2 Emmissions from Heating Fuels [18]

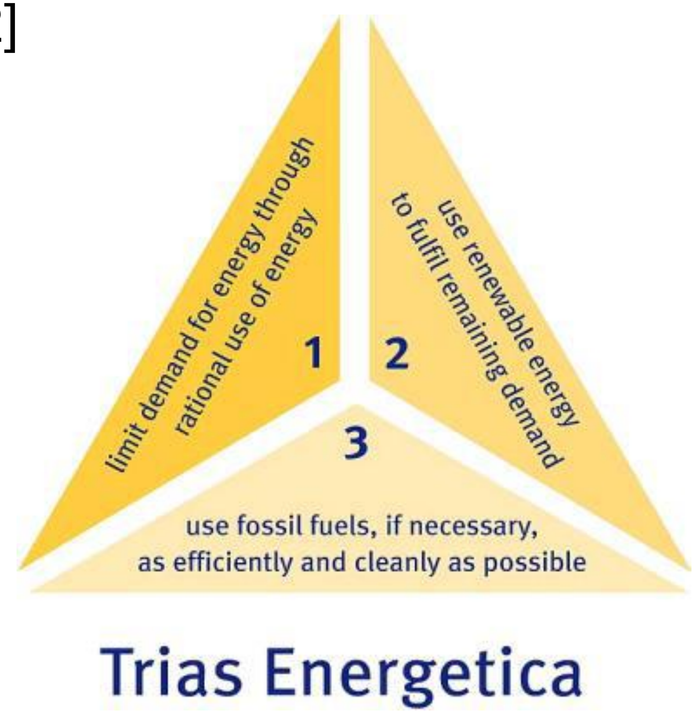


Note: Geothermal emissions are based on the electrical power coming from a fossil fuel power station

Introduction Cont.

Whilst member States are moving ahead with their targets and strategies for low energy buildings, the definition of low energy buildings varies significantly across Europe, one thing is common, the principles of the Trias Energetica [12]

1. Reduce energy need by limiting the demand for energy to a minimum.
2. Use **renewable energy** to fulfill remaining demand
3. High-efficient fossil fuel equipment can be used to cover peak loads (if not fully covered by renewable energy)



Module 9.1

Solar Thermal Water Heating Systems

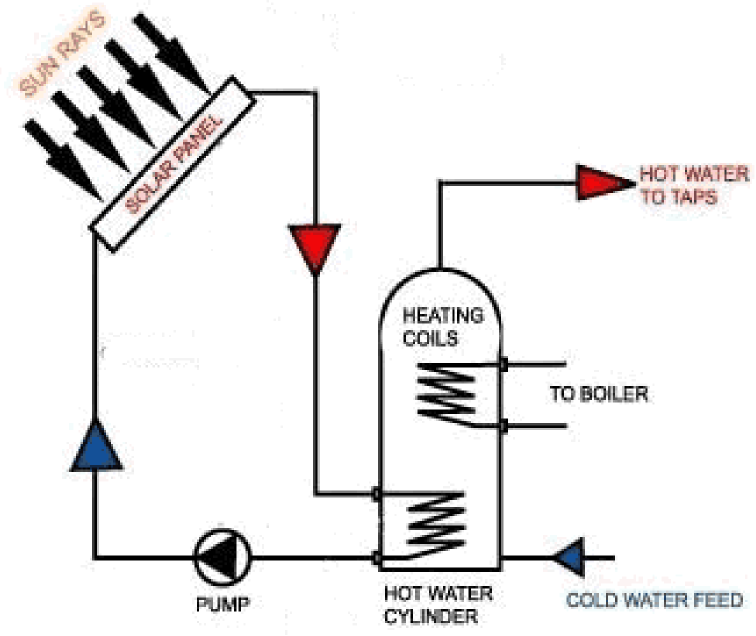
- **On completion of this module learners will be able to:**

  – Explain principles of solar thermal technology and outline different types of systems

  – Evaluate different collector technologies and detail the requirements of system design and sizing

Solar Thermal Technology

Solar thermal technology is converting the energy of the sun directly into heat, which is usually stored, using water as a media. The typical solar heating system consists of a collector; a heat transfer circuit that includes the fluid and the means to circulate it; and a storage system including a heat exchanger.



Application of Solar Water Heating

- Domestic Water Heating
- Space Heating
- Water Heating for Agricultural and Commercial Purposes
- Swimming Pools

The Environmental Argument

Solar systems make no contribution to the global greenhouse effect in terms of CO^2 emissions (except a very small amount from the electrical power used for pump and controller). A well designed solar water heating system installed in a domestic house which previously used an electric immersion heater to heat water can save up to 1 tonne of CO^2 emissions per annum.

Solar Radiation

- Energy from the sun in the form of ultra-violet, visible and infra-red electromagnetic radiation is known as **solar radiation**.
- Solar water heating technology is about capturing this energy and converting it into a form that can be used in buildings
- **Direct** beam radiation comes in a direct line from the sun.
- **Diffuse** radiation is scattered out of the direct beam by molecules, aerosols, and clouds.

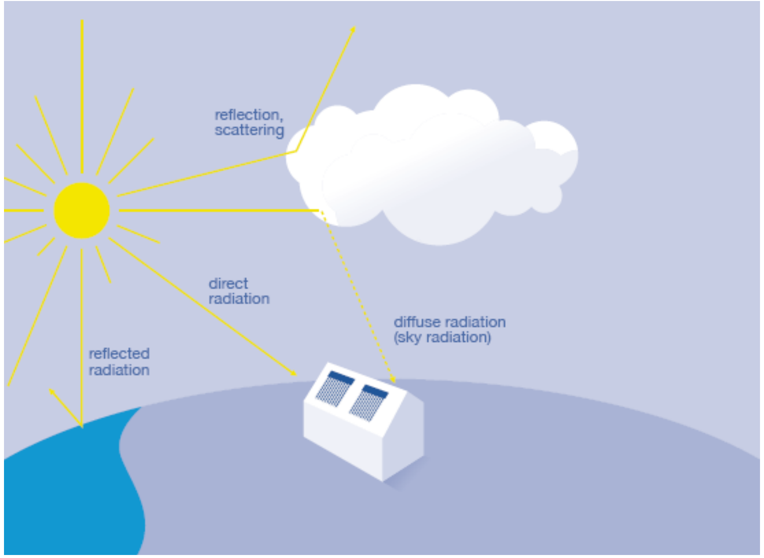


Diagram showing Global irradiation and its components [5]

- The sum of the direct beam, diffuse, and ground-reflected radiation arriving at the surface is called total or **global solar radiation**.

Solar Insolation Level

Solar Insolation means the amount of energy reaching the earth's surface per square meter. (KW/M2) The largest radiation values are over the equatorial zone because the Sun's rays are more concentrated.

The values are generally expressed in kWh/m2/day. This is the amount of solar energy that strikes a square metre of the earth's surface in a single day. Of course this value is averaged to account for differences in the days' length.

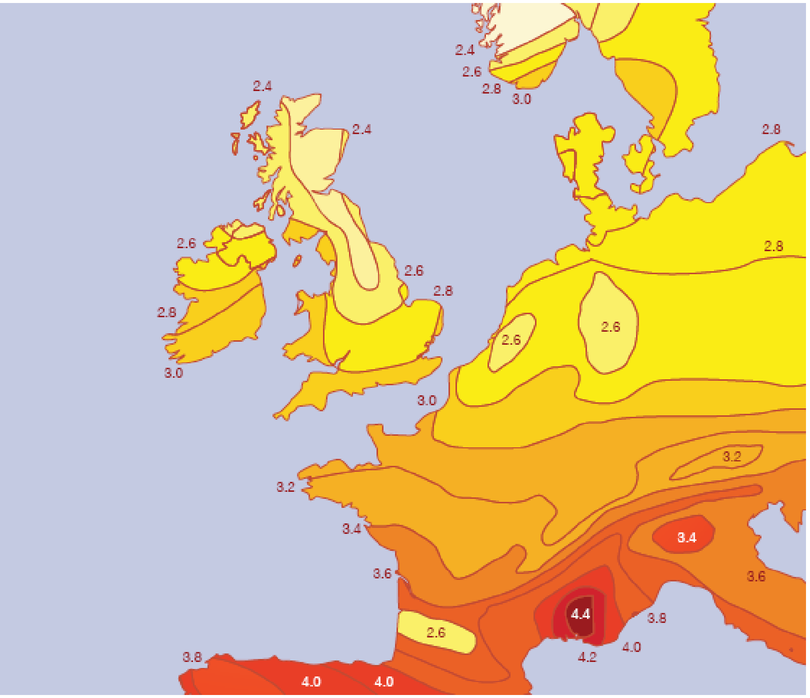


Diagram shows the average daily solar radiation acting on $1m^2$ in Northern Europe. Surface inclined at 30°, measured in kWh [5]

Evaluating a Site for Solar Energy

Orientation - In the northern hemisphere collectors should ideally face south. However, orientations between 30º east and 40º west of south are acceptable and will not result in more than 10% loss in efficiency compared with the ideal situation.

Angle of Inclination (azimuth angle and tilt angle) - The energy collected does not vary greatly with quite significant variations from the ideal position of facing south at an angle of 45º.
The annual energy collection only varies by a maximum of 10% for surfaces facing anywhere between 30º east of south and south west and tilt angles of 20º to 45º.
This flexibility means that a large proportion of existing buildings have roof orientations and angles suitable for solar energy systems.

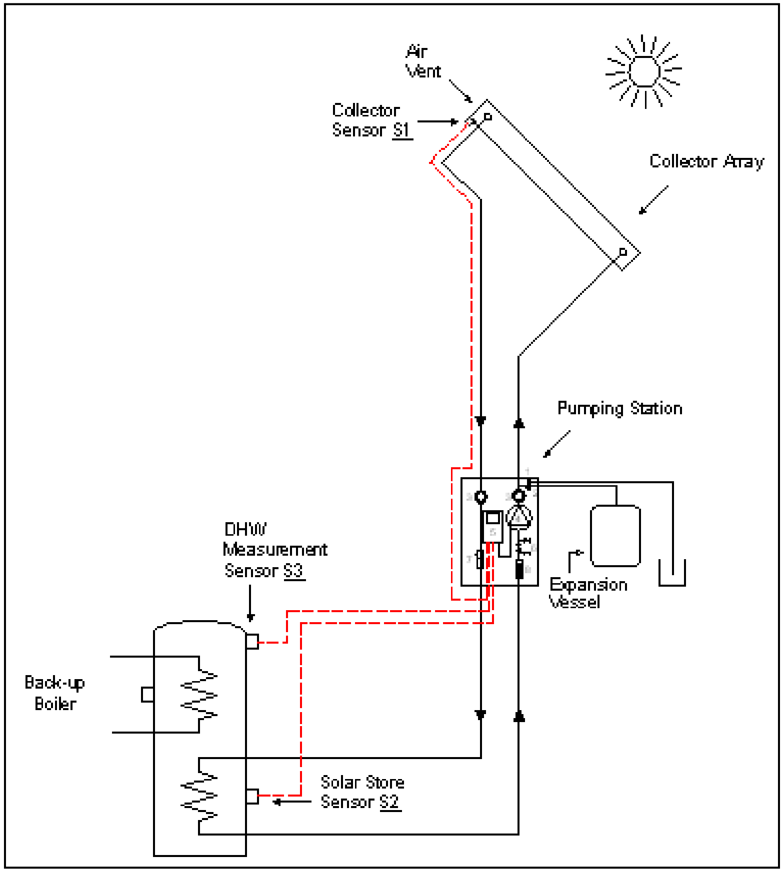
Shading - It is important that the collectors are positioned so there are no shadows on them during the day. The shading can be from the collectors themselves, or from trees, chimneys or Parts of buildings.

Types of Solar Water Heating Systems for Households

- Pressurised Indirect Primary Circuit
- Indirect Open-Vented (Pumped)
- Drain-back Systems
- Thermo Siphon Primary Circuit (Natural Circulation)

Systems Cont. - Pressurised Indirect Primary Circuit

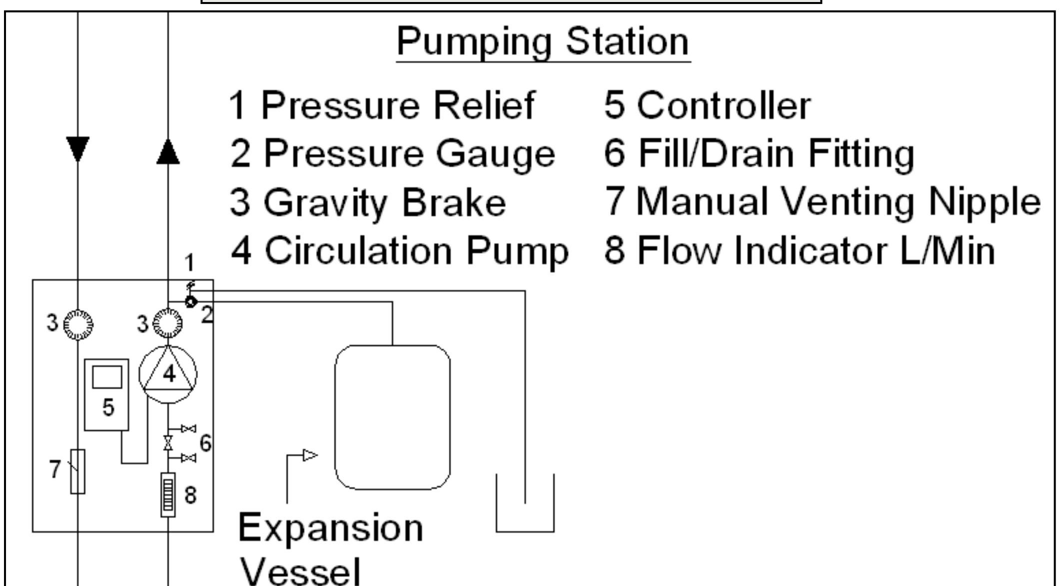
The principles of an indirect system are -
The collector panels absorb the solar radiation and the heat is transferred to a hot water storage cylinder by means of an indirect system, which uses a water/antifreeze solution as the heat transfer fluid. The pump, controlled by a differential temperature controller, circulates the heat transfer fluid from the collector panels through the heat exchanger in the hot water cylinder and back to the collector panels for re-heating. The temperature sensors of the differential temperature controller are situated at the collector panel outlet and on the hot water cylinder and ensure that fluid is only circulated when the fluid in the collector panels is hotter than in the cylinder.



Typical pressurised indirect system

Systems Cont. - Pressurised Indirect Primary Circuit

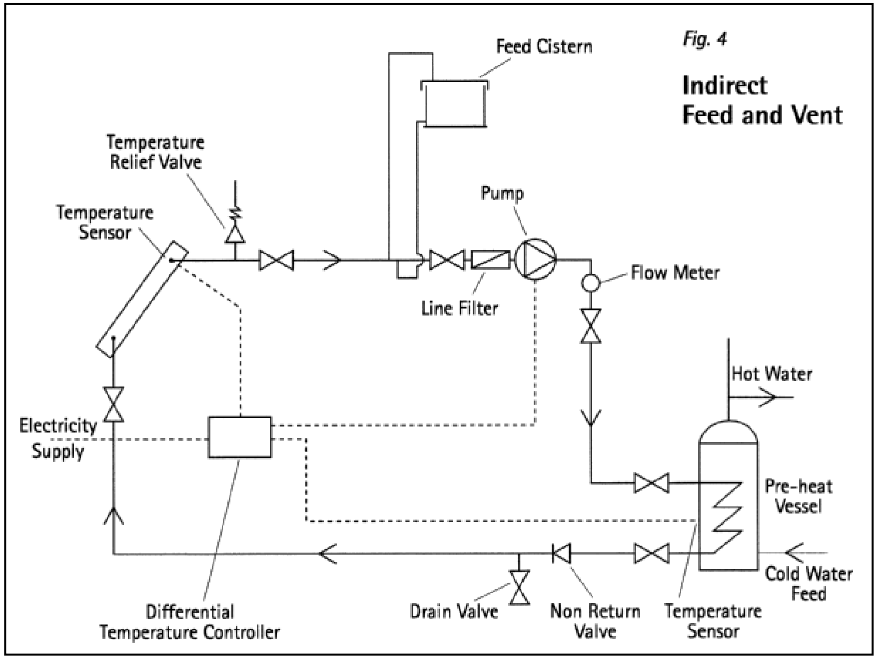
Typical Twin Line Pump Station



Systems Cont. – Indirect open-vented (Pumped)

Solar systems that use indirect open vented primaries, whist historically interesting, are seldom fitted in recent years

- Restrictions on collector and pump locations
- Emergence of high performance collectors and low pressure in circuit means that it is easier to boil

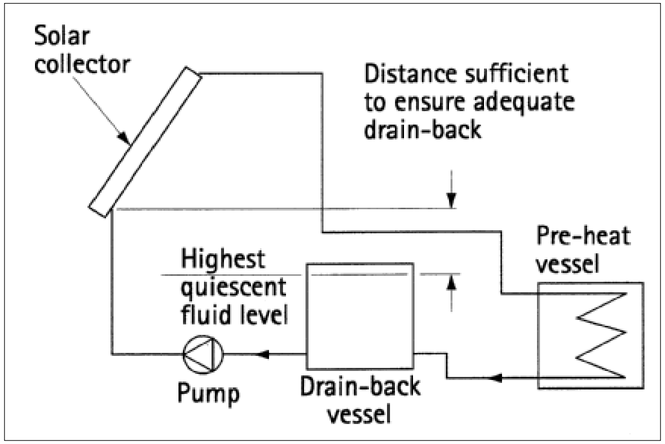


Typical indirect open-vented solar system [10]

Systems Cont. - Drain-back Systems

The heated fluid in the collectors is transferred to the pre-heat vessel by a circulating pump but once the pump switches off the fluid in the collectors drains back into a receiving vessel.

- No need for water / glycol mixture in the primary circuit to prevent freezing.
- To prevent overheating the collector also drains if the temperature in the storage tank exceeds 85°C.
- In case of a power failure the collector will automatically drain and the system will remain in a safe situation until the power is restored.

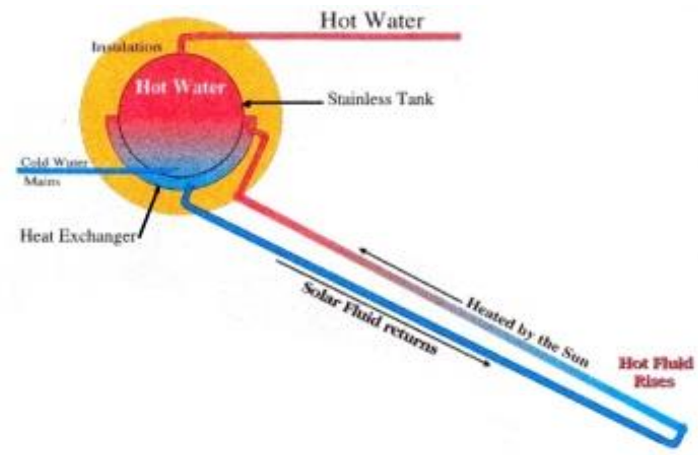


Typical Drain-back system [10]

Systems Cont. - Thermo Siphon Primary Circuit (Natural Circulation)

Thermo siphon systems rely on the natural convection of warm water rising to circulate water through the collectors and to the tank, which is located above the collector. As water in the solar collector heats, it becomes lighter and rises naturally into the tank above. Meanwhile, the tank's cooler water below flows down pipes to the bottom of the collector, causing circulation throughout the system.

- Inexpensive since there is no need for a circulation pump or a circulation control device.
- No electricity required to run system.



Solar Collectors

- The function of the collector is to collect the energy falling upon it and transfer it in the form of heat to the fluid in the collector.
- There are many variants of solar collectors. They essentially fall into two general categories:
  - Flat Plate Collectors
  - Evacuated Tube collectors

European Standards

- European standards for the testing of collectors have been defined for factory made collectors EN 12975
- Testing to the European Solar Keymark standard has become increasing the adopted norm and all compliant collectors are marked with the logo shown below. The Solar Key mark is a voluntry third-party certfication. As wall as EN 12975, certfication requires additional quality control and factory visits from the European Solar Thermal Industry Federation.

solar key mark

DIN CERTCO

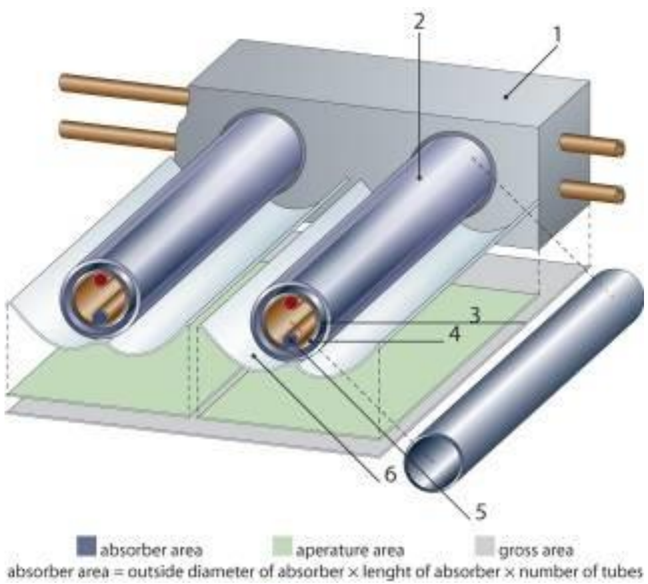
Collector Areas

In the interpretation of collector test certificates, manufacturer's datasheets or the outputs from system sizing, it is important to understand which collector area is being discussed

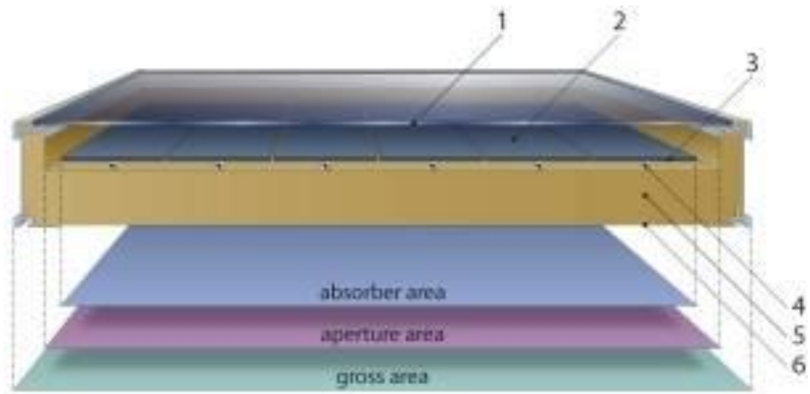
- The **Aperture Area** is the total area available for the absorption of solar radiation
- The **Gross Area** is the total size of the collector array
- The **Absorber area** is the actual area of black absorber, which is exposed to the sun

Collector Areas

Evacuated tube collectors [14]



Flat plate Collectors [14]



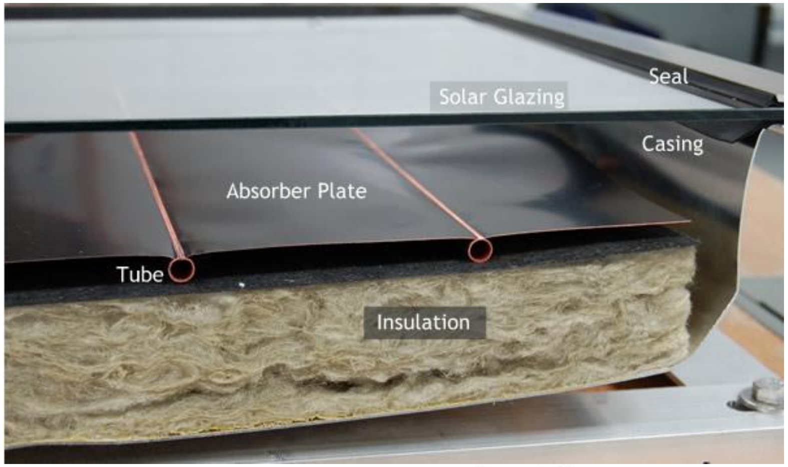
Solar Collectors- Flat plate

The key features of a glazed and insulated collector are:

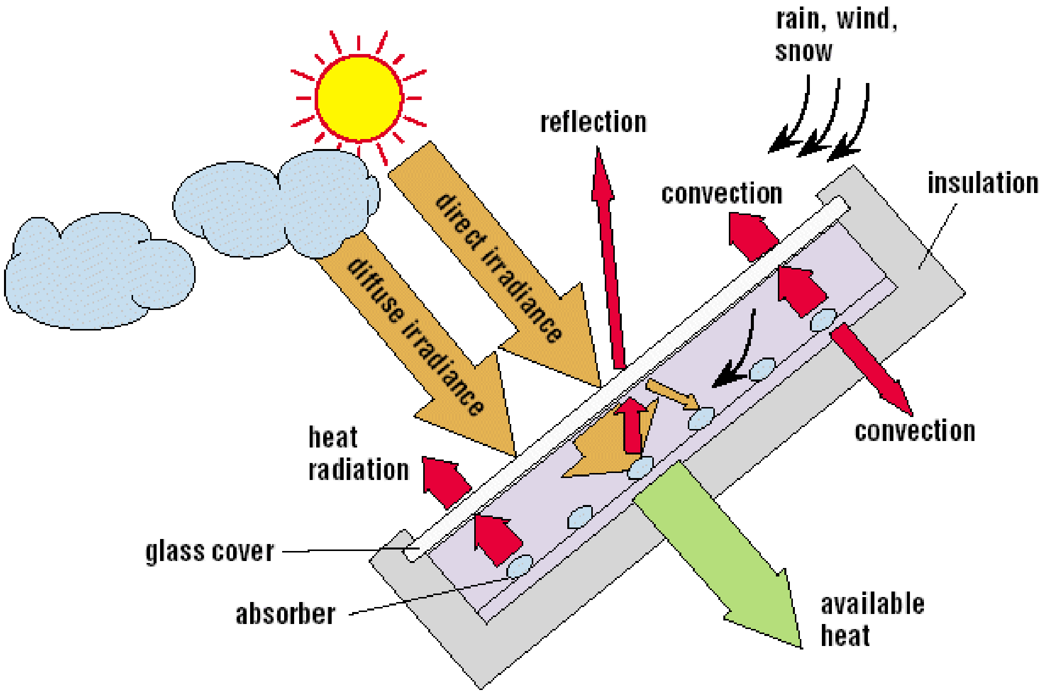
- Sunlight passes through the **glazing** and strikes the **absorber plate**, which heats up changing solar energy into heat energy. The heat is transferred to liquid passing through pipes attached to the absorber plate. Absorber plates are commonly painted with **"selective coatings,"** these coatings absorb UV and visible radiation, but are poor emitters of longer wave infrared so that they retain heat much better than ordinary black paint. Absorber plates themselves are made from copper, aluminium or stainless steel ultra-sonically welded to a copper pipe.

- **Insulation** (mineral wool) at the back and sides of the absorber plate.

- A **weather-proof casing** to protect the absorber plate and its insulation.



Solar Collectors- Flat plate



Vacuum Tube Collectors – Types of Construction

Single Wall Tube

A **clear single tube** contains a selective **flat absorber plate**, the tube is evacuated down to a vacuum-level normally encountered only in outer space. This virtually eliminates the conduction and convection heat losses, leaving only the radiation heat losses. These are minimised through the use of selective coatings which hinder the emission of infra-red heat radiation. This makes this type of collector very efficient at retaining heat and hence it is very good for high temperature applications.

Single wall tube [5]

Vacuum Tube Collectors – Types of Construction Cont.

Sydney Tube (double walled tube)

Each Sydney tube consists of two glass tubes made normally from borosilicate glass. The outer tube is transparent, the inner tube is coated with a selective coating (Al-N/Al) which absorbs the solar radiation and turns it into heat.

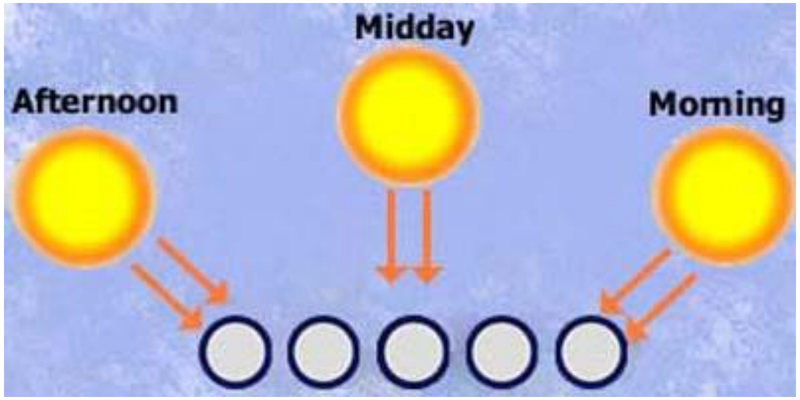
The top of the two tubes are fused together and the space between the two layers of glass is evacuated, giving vacuum-tube jacket, similar to a Thermos flask. The insulating properties (thermal efficiency) are Generally not as good as the single wall vacuum tube but are a lot better than the flat plate collector [9].

Double walled tube

Sydney Tube (double walled tube)

One advantage of the Sydney tube is its ability to **passively track** the sun. This gives it a more consistent output than any other collector over the whole day.

Note: as this tube has a **360º absorber**, it is able to provide an important and measurable increase in efficiency in the morning and afternoon when the sun's angle is between 40 and 80 degrees from perpendicular.

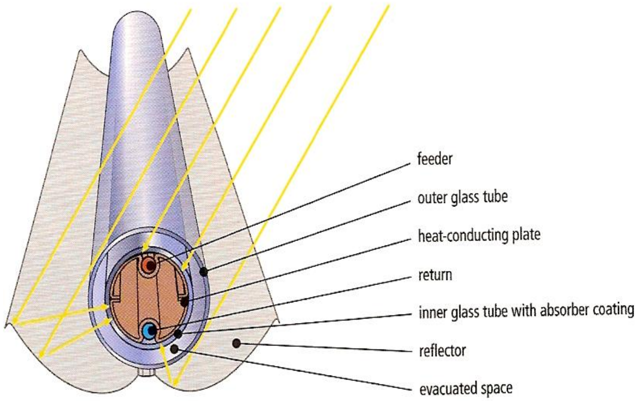


Tubes with a 360º absorber can passively track the sun

Compound Parabolic Collector (CPC) Variation

This is a variation on the Sydney type where a Curved reflector is added to the back of the collector. This shape of reflector is capable of reflecting the sun's rays onto the central tubular absorber, even as the sun tracks across the sky. The aperture area of the collector, is now the area of the reflector, but it can only lose heat through the vacuum tube and the manifold.

- The thermal characteristics of this type of collector are excellent.
- Dust and dirt may collect on the back of the vacuum tubes and on the reflector.

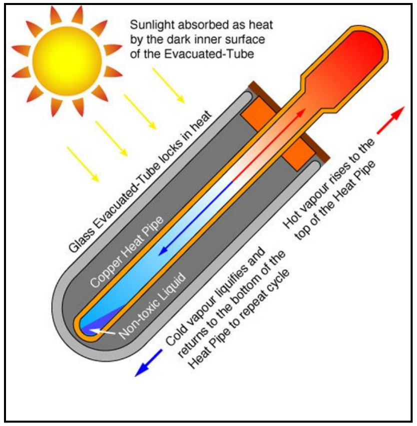


Reflecting the sun's rays

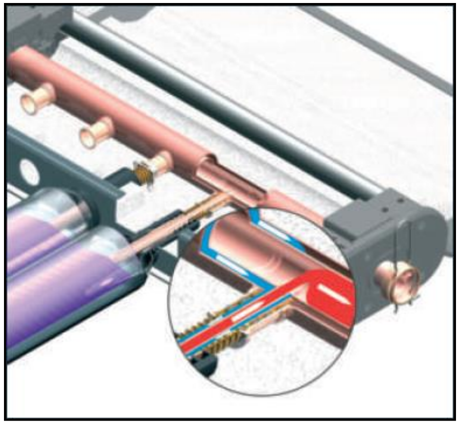
Extracting heat from the Vacuum Tube

There are two primary methods of extracting heat from the vacuum tube

- The first uses a sealed **heat pipe** clamped in a manifold whereas the second passes the anti-freeze mix through a copper pipe into the vacuum tube.
- The second method is known as **direct-flow tube, primary flow or primary fluid**.



Heat Pipe



Direct Flow

Flat Plate vs Evacuated Tube Solar Collectors/Panels

- Evacuated tubes perform better than flat plate systems when the ambient temperature is low, i.e. in winter.
- Some people believe that flat plate solar collectors are more aesthetically pleasing.
- Flat plate is generally less expensive
- Evacuated tube collectors are lighter and easier to fit
- Flat plate are more robust
- Many Evacuated tube collectors' passively track the sun
- Flat Plate very rarely need repairs done to them, however if something does break (such as glass), the installer will usually need to replace the entire collector. Though Evacuated tube collectors are more prone to breaking, the tubes can be replaced individually without having to replace the entire collector

Collector Efficiency

There are several factors, which determine the heat output of a solar heating system. These include:

- Intensity of solar radiation
- Location and orientation of the collectors
- Aperture area of solar collectors
- Efficiency of the solar collectors
- Type of system to which it is connected (size of water heater etc)

Collector Efficiency Cont.

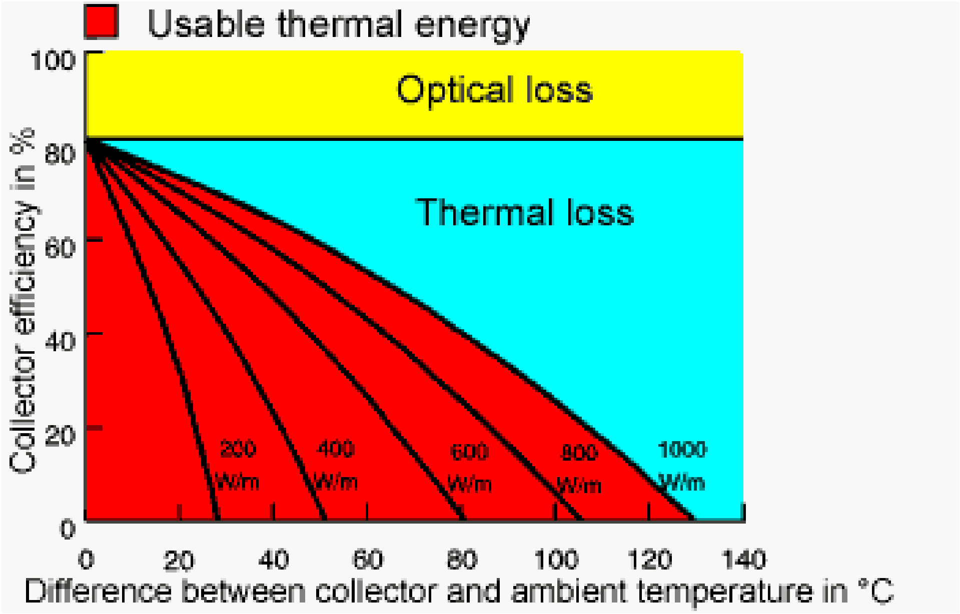
The Efficiency of Collector Equation

As the collector heats up, it begins to lose heat from the walls and the back as well as through the front face of the collector. The hotter the collector gets in comparison to the ambient temperature, the more heat it will lose. This reduces the efficiency of the collector. The efficiency of a solar collector can be calculated using the following equation:

$$\%Eff = \eta_0 - a_1 \frac{(T_m - T_a)}{G_k} - a_2 \frac{(T_m - T_a)^2}{G_k}$$

Collector Efficiency Cont.

η0 is the optical efficiency of the collector. This is a measure of how good the collector is at absorbing solar energy. It assumes the collector is at the same temperature as the ambient surroundings.



Graph shows how collector output is effected by temperature differences between inside and outside the collector [10]

Collector Efficiency Cont.

- **a_1** is usually called the linear loss co-efficient. It is similar to a U-value and is a measure of how much heat the collector loses (mainly by conduction) as it's temperature rises relative to the surrounding ambient air temperature. Units are W/m^2K.

- **a_2** is usually called the quadratic loss co-efficient. It is a measure of how much heat the collector loses (mainly by convection and radiation) as it's temperature rises relative to the surrounding ambient air temperature. This type of heat loss becomes more significant at higher absorber temperatures. Units are W/m^2K.

- **T_a** is the surrounding ambient air temperature in °C.

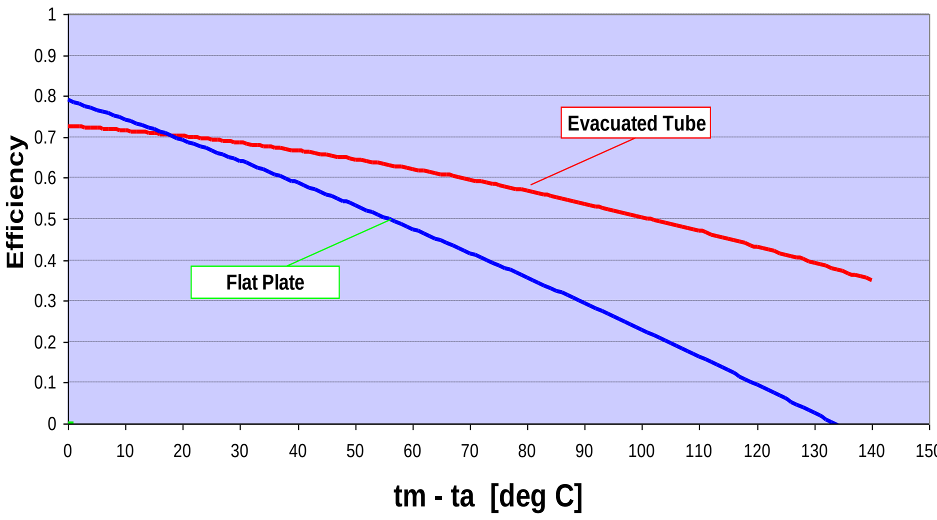
- **T_m** is the mean temp of the collector in °C.

- **G_k** is the solar irradiation in W/m^2

Collector Efficiency Cont.

Differences Between Collector Types

Flat panel collectors tend to have a higher optical efficiency than Evacuated tube collectors. However, they also usually have higher heat losses i.e. a1 and a2 loss coefficients.



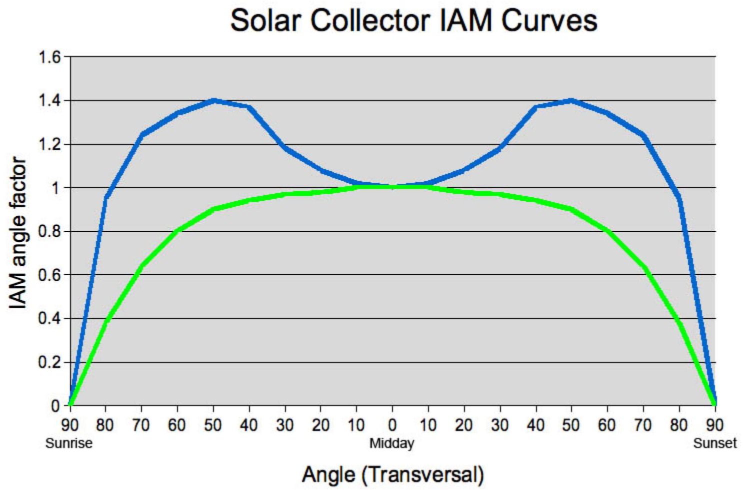
Graph shows the efficiency of Glazed Flat Plate versus Evacuated Tube collectors at various temperature differences between ambient air (T_a) and the water within the collector (T_m)

Collector Efficiency Cont.

Incidence Angle Modifier (IAM) - When Solar Collectors are tested, performance measurements are taken with the solar irradiance measured at right angles to the collector plane. IAM is the variance in output performance of a solar collector as the angle of the sun changes in relation to the surface of the collector. 360º evacuated tube absorbers provide an important and measurable increase in efficiency in the morning and afternoon when the sun's angle is between 40 and 80 degrees from perpendicular.

Graphical representation showing the increase in efficiency provided when collectors can passively track the sun in the morning and evening.

- *Flat absorber-green*
- *360º absorber-blue*



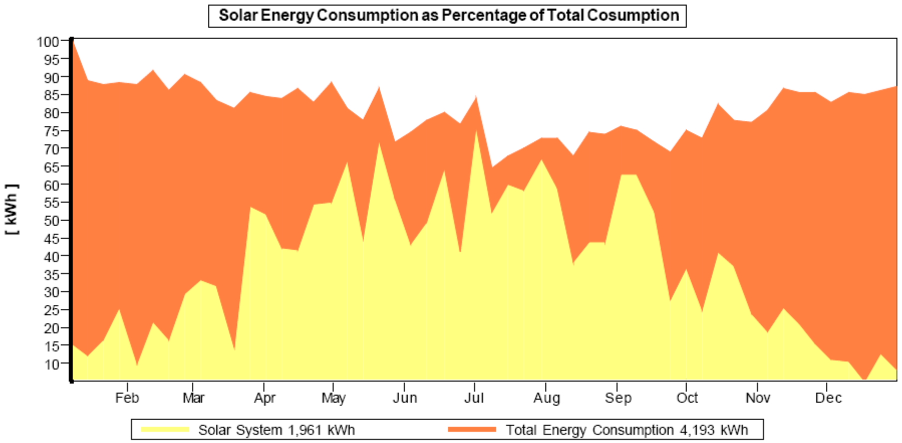
System Sizing – Hot Water

Solar fraction (%) = yearly contribution to hot water demand

Desired Solar Fraction

- Depending on climate (summer / winter)
- Depending on load distribution over the year
- Small systems / standard situations: rules of thumb
- Large / special conditions: simulation

The graph shows how a solar system performs in a typical dwelling situated in northern Europe (Dublin), the system is sized to provide nearly half the annual hot water requirements (DHW Solar Fraction: 46.8 %). This calculation were carried out by T*SOL Pro 4.4 - Simulation Programme [17]



System Sizing Hot Water Cont.

Size of solar array - For a system designed for the northern European climate, an estimate for the collector surface area can be made under the following assumptions.

- The daily hot water use is between 35-65 litres (45^{o}C) per person.
- Desired solar fraction approximately 50-60%.
- Collector orientated between SE an SW.
- Collector pitched between 30^{o} and 55^{o}.
- Little or no shading on collector.

System Sizing Hot Water Cont.

The design goal is to cover the hot water load almost completely in the months with high irradiation (summer time).

According to REIA [9], the **rule of thumb** for such situation is:

- 1 - 1.5m^2 of flat-plate collector per occupant
- 50 - 70 litres of storage per m^2 of flat plate collector

Module 9.2

Heat Pump Water Heating Systems

- **On completion of this module learners will be able to:**
  - Explain the principles of geothermal energy and determine how the efficiency of heat pumps is measured
  - Outline the alternative methods of heat source collection and understand the ‘evaluation of site characterisation’

Geothermal Energy

Geothermal energy is a term used to describe the energy available from the earth. Geothermal energy can generally be divided into two forms:

- high temperature/deep geothermal
- low temperature

This section will only deal with **low temperature geothermal** and in particular with the technology of heat-pumps. High temperature geothermal systems typically use the high temperatures available in the earths crust to produce hot water or steam directly.
Low temperature geothermal normally requires the use of **heat pump technology** to upgrade the heat available and the typical application is for water or space heating. Heat pumps can draw their energy from the ground, water or air.

Geothermal Energy Cont.

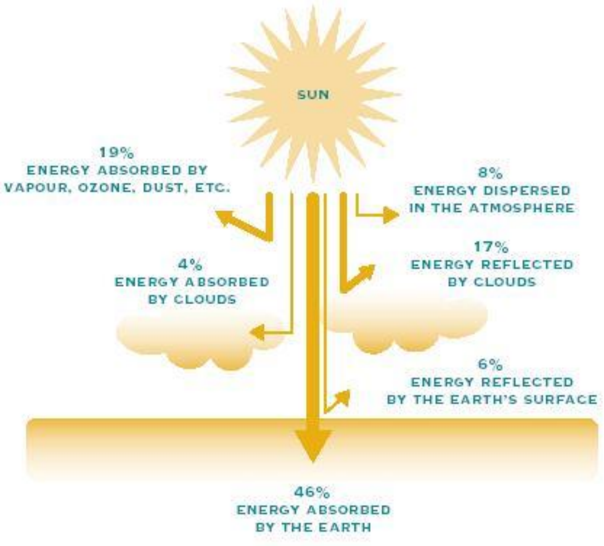
Heat is widely available in the ground, air and water. These natural sources of heat are constantly replenished by the sun, wind and rain. A heat pump system will harness these free and renewable energy sources for heating dwellings and supplying hot water at a very low cost.

The role of the heat pump is to **'pump up'** heat from a low temperature source, for example the ground under a lawn and release it at a higher temperature into the central heating system.

There are three main types of heat pump available on the market, those that take heat from the ground, from **water** (rivers or wells) or directly from the **air**.

Geothermal Energy Cont.

Geothermal technology relies on the fact that the earth remains at a relatively constant temperature though-out the year, warmer than the air above it during the winter and cooler in the summer very much like a cave. The Figure illustrates how the radiation from the sun is distributed. Due to the density of the earth and its insulation properties, it absorbs almost half of the total radiation. The geothermal heat pump takes advantage of this by transferring the heat stored in the earth or in the ground water into the building during the winter



Distribution of solar energy to earth [21]

Basic Operating Principle

There are three main parts of any GSHP system:

1. A heat source and a means of extracting heat.
2. The heat pump
3. A distribution system

1. Heat Source

The heat source can be the ground, ground water or surface water. Energy in the form of heat is present even at very low temperatures. Provided the temperature of an object is above absolute zero (–273°C), there is some heat energy present in the object. The temperature of these heat sources is too low to heat a building directly, but they still hold a vast store of heat. Heat is extracted from the heat source through a collector and transferred to the heat pump via a liquid (water or antifreeze solution).

Basic Operating Principle Cont.

2. Heat Pump

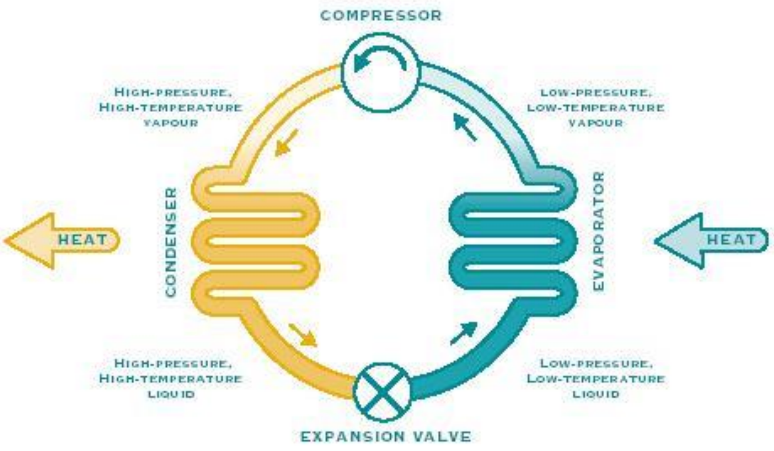
The heat pump uses a basic refrigeration cycle to extract heat from the collector and raises the temperature for use in the building, using a relatively small amount of electricity.

3. Distribution System

The distribution system takes the heat from the heat pump and delivers it to the end-use. Because GSHPs raise the temperature to approximately 40°C they are most suitable for underfloor heating systems, which require temperatures of 35 to 40°C, as opposed to conventional boiler systems, which require higher temperatures of 60 to 80°C. The climatic conditions in Ireland and Central/Northern Europe are such that by far the most demand is for space heating and air conditioning is rarely required. Therefore unlike GSHPs in USA, the heat pumps mainly operate in the heating mode only.

The Refrigeration Cycle

The heat pump extracts heat from the fluid circulating in the collector. It works on the same principle as a refrigerator, that is, the vapour compression refrigeration cycle. The main components in such a heat pump system are the **compressor**, the **expansion valve** and two heat exchangers referred to as the **evaporator** and the **condenser**. The components are connected to form a closed circuit, as shown in the figure. A fluid with a boiling point lower than the heat source temperature serves as a medium for heat transport; it is called the working fluid or refrigerant.



The Refrigeration Cycle - Heating Mode

The Refrigeration Cycle Cont.

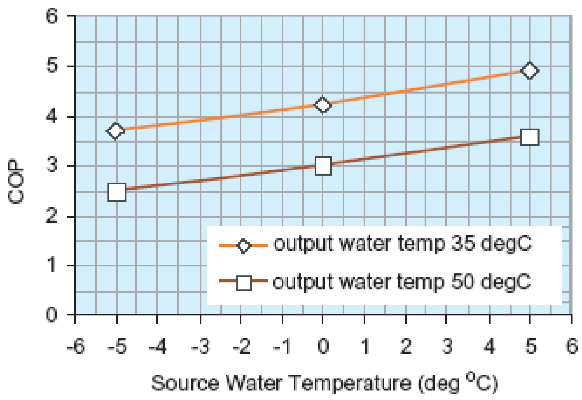
- In the evaporator, refrigerant enters in a cool, mostly liquid state. The temperature of the liquid is lower than the temperature of the heat source. The warmer ground then causes the liquid refrigerant to evaporate, thus absorbing heat.
- Refrigerant vapour from the evaporator travels to the compressor where it is compressed to a higher pressure and temperature.
- Once it passes through the compressor, the hot vapour then enters the condenser, where it condenses and gives off heat to the distribution system.
- Finally, the pressure of the warm liquid refrigerant exiting the condenser is reduced through the expansion valve. The expansion process also reduces the refrigerant temperature before it re-enters the evaporator.

TRAINENERGY

Heat Pump Performance

Energy is needed to activate the heat pump cycle and to compress the vapour for the production of useful heat.

- The efficiency of a ground source heat pump system is measured by the **coefficient of performance (COP).** This is the ratio of units of heat output for each unit of electrical energy input (compressor and pump for heat source)
- Average COP is around 3-4 although some systems may produce a greater rate of efficiency. This means that for every unit of electricity used to pump the heat, 3-4 units of heat are produced, making it an **efficient** way of heating a building.
- **COP varies** according to the difference between the temperature at which the pump takes in heat from the outside world and the temperature at which it puts the heat out into the building.
- **Seasonal Performance Factor (SPF)** is defined as the mean COP



COP of typical small GSHPs [11]

Alternative methods of heat source collection for GSHPs

Ground source heat pump (GSHP) come in a wide variety of configurations that use the ground, ground water or surface water as a heat source. Examples are [1]:

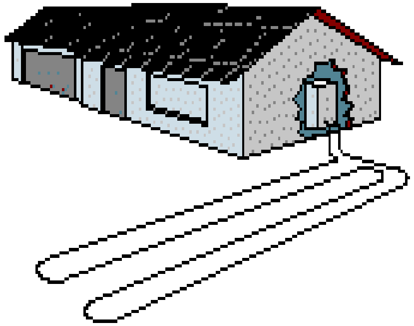
- **Ground-coupled heat pumps (GCHP):** use the ground as a heat source and sink either with vertical or horizontal ground Collectors
- **Ground-water heat pumps (GWHP):** use underground (aquifer) water as a heat source.
- **Surface-water heat pumps (SWHP):** use surface-water bodies (lakes, ponds, etc.) as a heat source.

Alternative methods of heat source collection for GSHPs Cont.

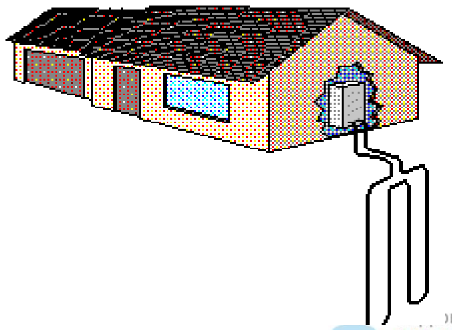
Ground-Coupled Heat Hump (GCHP)

Ground-coupled heat pumps are a subset of ground-source heat pumps (GSHPs). The distinguishing feature of GCHPs is that they are connected to a closed-loop network of tubing that is buried in the ground. The most common method of ground-coupling is to bury thermally fused plastic pipe either horizontally or vertically. The Figures below demonstrates closed loop horizontal and vertical collectors [13]. A water or antifreeze solution (brine) is circulated through the inside of the tubing and heat is absorbed from the ground.

Horizontal



Vertical



Alternative methods of heat source collection for GSHPs Cont.

In countries of low temperature geothermal resources, the earth's crust offers a steady and large energy source. Regeneration of soil temperatures is based on a number of factors including **air temperatures** and daily **solar radiation**. The influence of the climate on ground temperatures in northern Europe is apparent, as the average ground temperatures at depths of:

- 1m and greater are between 8-12^{o}C.
- From 6-9m the temperature of the soil does not fluctuate more than 1-2^{o}C over the year
- From 10-100m, the soil temperature is close to the mean air temperature

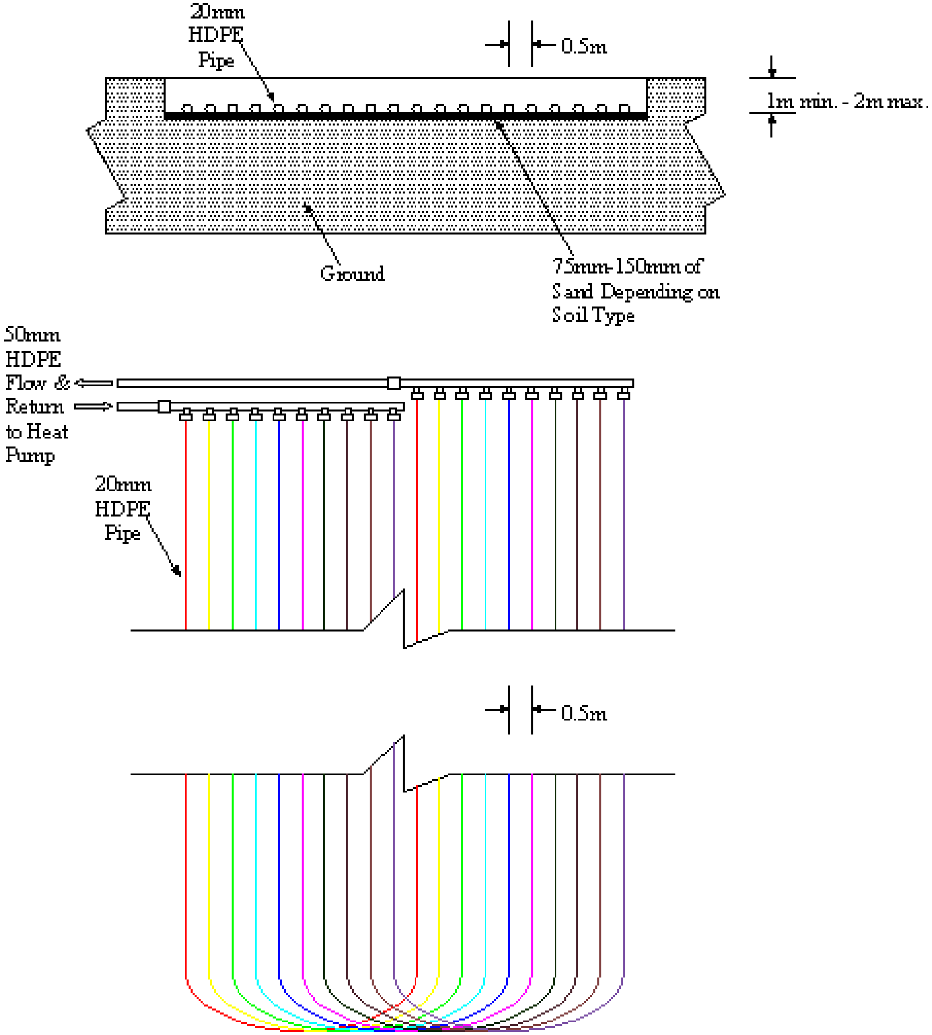
TRAINENERGY

Alternative methods of heat source collection for GSHPs Cont.

Horizontal Closed Loops (Irish soil conditions)

As a rule of thumb :

- The ground area required for the collector is approximately 2 times that of the floor area of the dwelling to be heated.
- Each collector loop no more than 100m.



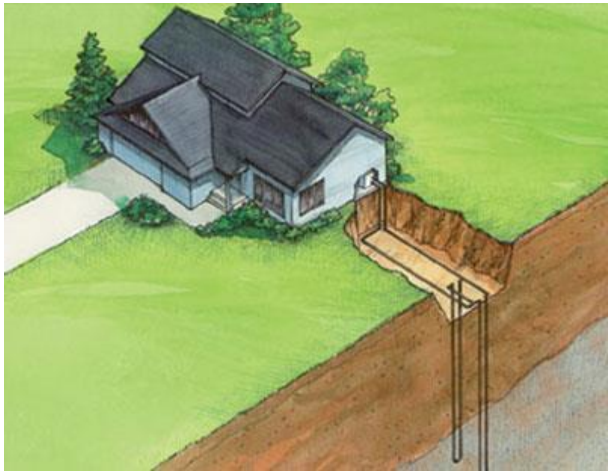
Horizontal Closed Loop Collector

Alternative methods of heat source collection for GSHPs Cont.

Vertical Closed Loops

Vertical loops are generally more expensive to install, but require less piping than horizontal loops because the earth deeper down is warmer in winter. Solar radiation will affect the earth to a depth of about 10m, causing a cycling of soil temperatures that lags in time and decreases with depth due to the insulating properties of the soil. Vertical loops are controlled by the mean annual temperature and thus, have a more stable temperature environment

- Each hole contains a single loop of pipe with a U-bend at the bottom.
- After the pipe is inserted, the hole is backfilled or grouted.



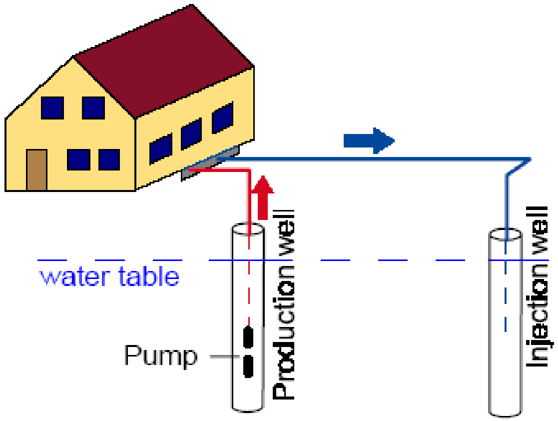
Vertical Closed Loop Collector

Alternative methods of heat source collection for GSHPs Cont.

Groundwater Heat Hump (GWHP)

The distinguishing feature of GWHPs is that they are connected to a vertical borehole open loop collector. Groundwater utilised as a heat pump source is accessed in much the same way as normal water supplies and it is possible to use the same borehole for both. In this type of system, ground water from an aquifer is pumped directly from the well (production well) to the building, where it transfers its heat to a heat pump, after it leaves the building, the water is pumped back to the same aquifer via a second well (injection well) as shown in the figure below.

Vertical borehole open loop collector [13]



Alternative methods of heat source collection for GSHPs Cont.

Surface water Heat Hump (SWHP)

Surface water heat pumps (SWHPs) are also included as a subset of GSHPs because of the similarities in application and installation methods. SWHPs can be either closed loop similar to GCHPs or open loop systems similar to GWHPs.

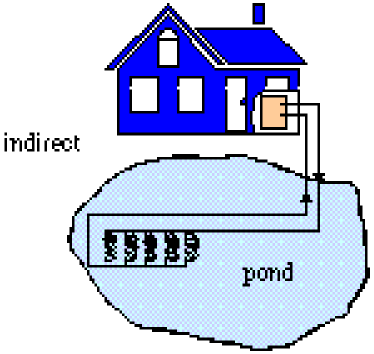
The performance of lakes/ponds as a heat source is dependant on size (depth, surface area) and temperature, a detailed analysis should be preformed to ensure the resource can support the heating load of the building. For example deeper lakes with continuous flow can support greater loads.

Alternative methods of heat source collection for GSHPs Cont.

SWHP - Lake/Pond Closed Loop systems

In a closed system, the heat pump is linked to submerged coils. Heat is exchanged from the lake/pond by the fluid (water-antifreeze mixture) circulating inside the coils. The recommended piping is the same thermally-fused high density polyethylene (HDPE) tubing used in ground-coupled loops. Piping sizes range from 20mm for use in protected lakes/ponds to 25mm for use in lakes/ponds where a thick pipe wall may be required because of potential damage.

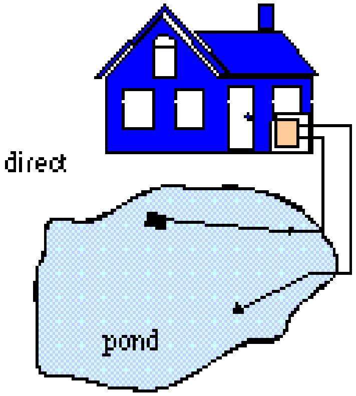
The HDPE coils are fused to the headers, pressure tested, floated into position, and sunk to the bottom of the reservoir. Placing the coils at 7m centres and at least 3m depth (lowest seasonal level) insures no thermal interference between coils and avoids cold pockets. [1]



SWHP Closed Loop Collector [6]

Alternative methods of heat source collection for GSHPs Cont.

SWHP - Lake/Pond Open Loop systems
In an open loop system, water is pumped from the lake/pond through a heat exchanger and returned to the lake/pond some distance from the point at which it was removed. The pump can be located either just above or submerged below the lake water level.



SWHP Open Loop Collector [6]

Alternative methods of heat source collection for GSHPs Cont.

Air Source Heat Pumps

Air source heat pumps use the same refrigeration cycle as ground source heat pumps to absorb heat from the outside air. The outside air flows directly through the heat pump evaporator.

- Heat pumps lose their efficiency as external temperatures fall. In colder climates the system needs to be installed with an auxiliary source of heat to provide heat at low temperatures or if the heat pump should require repair.
- While, Air-source heat pumps, however, achieve on average 10-30% lower seasonal performance factor (SPF) than ground-source heat pumps, air source heat pumps provide significant installation cost benefits over ground source systems. They are cheaper to install as there are no requirements for expensive ground loops to be installed.

Air Source Heat Pump

Alternative methods of heat source collection for GSHPs Cont.

Direct Exchange (DX) Heat Pump

A direct exchange (DX) geothermal heat pump system is a Geothermal heat pump system in which the refrigerant circulates through copper tubing placed in the ground. The refrigerant exchanges heat directly with the soil through the walls of the copper tubing. This eliminates the plastic water pipe and water pump to circulate water found in a water-source geothermal heat pump. This simplicity allows the system to reach high efficiencies while using a relatively shorter and smaller set of buried tubing, reducing installation cost.

Direct exchange (DX) Collector

Site Characterisation: Evaluation of Site's Geology, Hydrogeology, and other characteristics

- Presence or absence of water
  - Determines whether groundwater or surface water heat pumps can be used
- Depth to water
  - Affects drilling costs for open loop GWHP
- Water (or soil/rock) temperature
  - Affects required flow rate (open loop GWHP) or heat exchanger length (closed loop systems)
- Depth of rock
  - Influences drilling costs, borefield layout (closed loop)
- Rock type
  - Affects thermal conductivity
  - Affects drilling costs
  - Affects feasibility of certain system types
- Land area available
  - Determines whether horizontal or vertical collector can be used

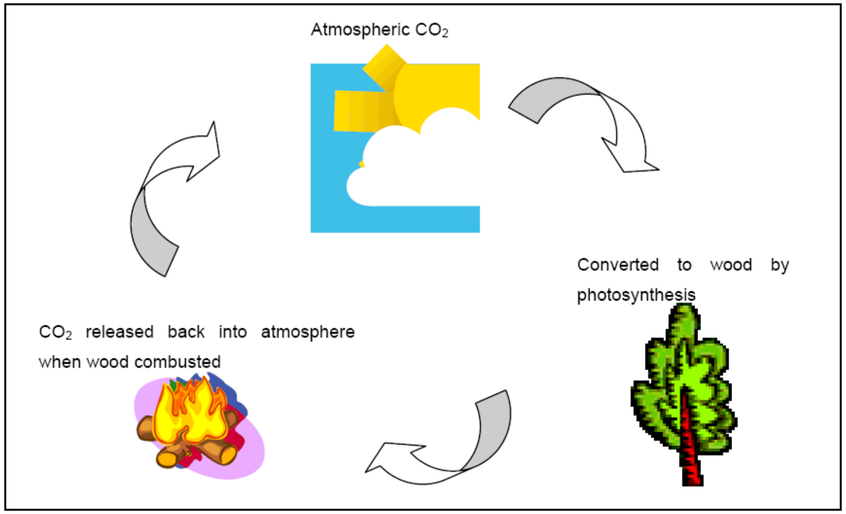
Module 9.3

Biomass Water Heating Systems

- **On completion of this module learners will be able to:**
  - Explain principles of Biomass technology and evaluate and compare log, wood pellet and wood chip technologies
  - Detail the requirements of fuel storage and explain the operating principles of solid biomass boilers

Stored Solar Energy

Plants (including trees) convert sunlight into plant matter (including wood). Wood is, in effect, stored solar energy. This energy can be re-released for human use with the right technology. Using wood as a fuel does produce carbon dioxide (the main greenhouse gas) but this CO^2 contains carbon that was absorbed relatively recently from the atmosphere by the growing tree . The combustion of fossil fuels, in contrast, releases carbon that has been locked away for millennia. Provided that existing forest carbon stocks are not reduced, replacing fossil fuels with Wood fuel from sustainable sources reduces CO^2 emissions.

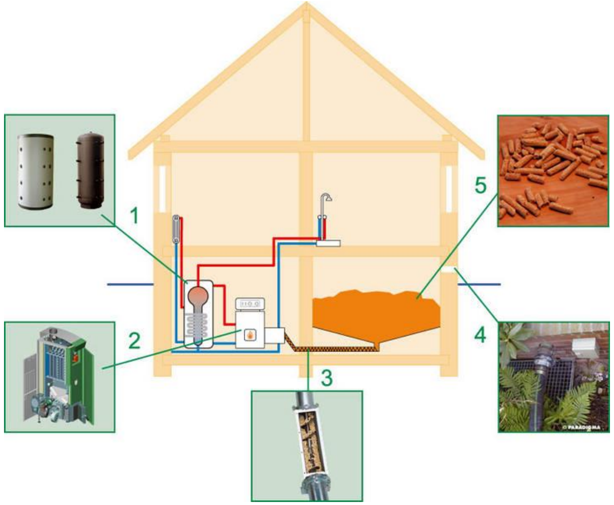


The cycle of carbon in a wood energy system

Solid Biomass Technology

The energy released during the combustion of solid biomass in modern heating systems is utilised very efficiently. Wood is the primary energy source, particularly in the form of split **logs, wood chips and pellets**.

Manual, partially automated or fully automated furnaces and boilers with electronically regulated firing systems have been developed to burn the wood. The firing systems in these new units achieve a very high degree of efficiency of up to 90 % and produce low levels of emissions.



Function diagram of a pellet heating system [19]

Solid Biomass - Logs

Logs: Burning wood logs is usually restricted to rural, wooded areas with urban dwellers finding supply limited and seasonal. Also, because the fuel is usually loaded manually and daily attention is required. One advantage is that, other than keeping the logs dry and clean, there are no special storage requirements.

Solid Biomass - Pellets

Pellets: these are free-flowing and high density, so are ideal for automated domestic systems where fuel storage space is limited. Wood pellets are made from wood shavings and sawdust and are used in highly efficient and convenient automatic wood boilers. Because they have a low moisture and ash content wood pellets burn very efficiently. What's more they are compact and easy to store. Typically pellets come in bags (ideal for stoves or smaller boiler systems) or are delivered in bulk by truck (ideal for boiler systems with bulk stores).

Solid Biomass – Wood Chips

Wood chips come from cut wood from forestry logging residues, purpose grown energy willow or as a co-product from industrial wood processing.

Chips are small pieces of wood that are 5-50 mm long (measured in the direction of the fibre). There may also be some longer twigs and finer material among them. The quality of the chips depends on the raw material and the chipping process (sharp chipper blades).

Two main sources for chips are available:

1. Chips from the sawmill industry: should have a maximum water content of 30% and be of uniform quality and size.
2. Forest chips: Given their water content of between 40% to 60%, they can only be used in large boilers unless they are dried.

Fuel Choice - Pellets Versus Chips

Pellets and chips have various advantages and disadvantages that have to be weighed up. Which fuel is used will depend very much on local conditions. Preferably systems should be installed, that can use both fuels and can therefore respond flexibly to the future market situation. Some of the main advantages and disadvantages are outlined below.

Chips

Advantages

- Local availability
- Favourable effect of production on the local job market
- Cheaper than pellets

Disadvantages

- Larger storage space required
- High, uniform fuel quality is important but possibly difficult to obtain
- More work required for the system

Pellets

Advantages

- Standard fuel – greater reliability
- Smaller fuel store
- Less service and maintenance

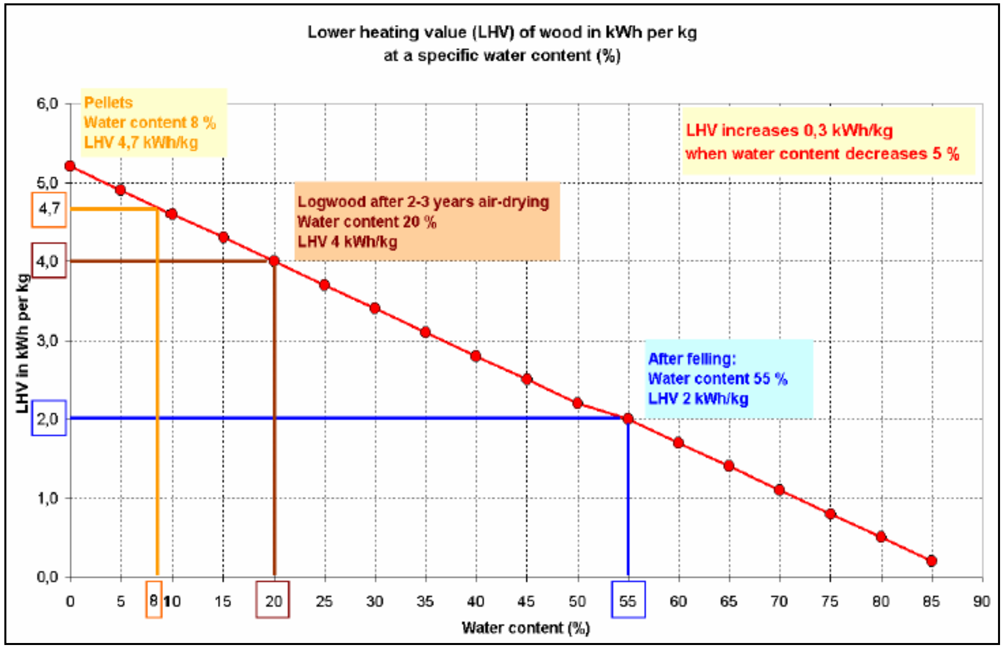
Disadvantages

- Less favourable for the local economy
- Higher fuel costs than for chips

Moisture Content

Moisture content of wood has a significant impact on the calorific or energy value of the fuel. The moisture content of wood is evaporated as it burns – that process requires energy, so the higher the moisture content the greater the amount of energy required for evaporation.

Domestic firewood (logwood) should be seasoned for at least one year, and preferably two, before being used. The wood used to produce wood chips should be allowed to dry before being chipped. The sawdust used to produce wood pellets is dried before pelletising.



This diagram shows the relationship between moisture content and energy content [20]

Calorific Value Equivalents

1000 l heating oil (10 kWh/l)

≈

5 – 6 stacked m^3 logs (hardwood)

7 – 8 stacked m^3 logs (softwood)

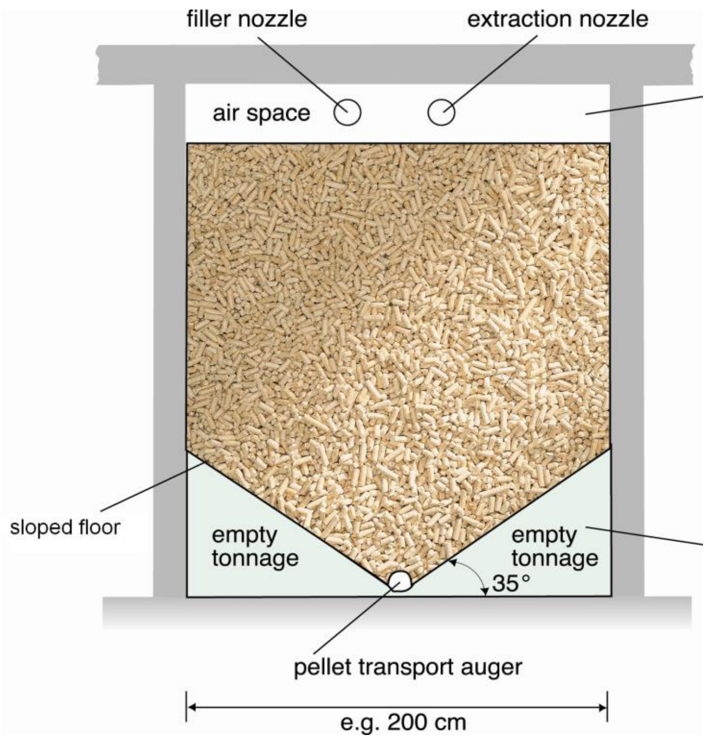
10 – 15 bulk m^3 wood chips

~ 2000 kg wood pellets

Source: REIA [7]

Storage for wood pellets

- Rectangular
- Dust-proof
- Protected against moisture
- National or regional fire protection
- Walls must bear the corresponding static loads
- Two metal nozzles for delivering the fuel and removing the venting air
- Installations at least concealed or protected against mechanical load
- A sloped floor can help to allow maximum and easy emptying, allowing pellets to slide towards the conveyor system
- Deflecting mat



Cross-section of pellet storage room [7]

Storage for wood Chips

Possibilities for storing wood chips

As wood chips are not a free flowing material and bridging is a common occurrence in bunkers and silos, simple agitators are fitted into the storage unit to facilitate removal, such as the floor-level rotary-blade stirrer shown opposite

Boilers

Wood pellet/chip boilers can be located in a purpose built boiler house or garage. They can also be placed outdoors if housed in an insulated weather casing.

Boiler efficiency depends on the burnout rate, on the boiler surface temperatures and the exhaust gas temperature. Modern boilers achieve efficiencies beyond **90 % at full load**, which decrease, however, at part load.

The standard **EN 303-5** is already in use for solid fuel-fired boilers. It gives requirements and instructions for measuring power, efficiency and emissions. It should be noted that efficiency and emission requirements in these standards are only the basic requirements. Any country or part of a country can specify higher demands.

Generally approved **CEN standards** give instructions on how to evaluate these demands. This will help manufacturers who export their products to many countries. In the future, testing will only be needed in one notified laboratory.

Typical Boiler Features

Typical user-friendly automation [18]:

- Electric hot air ignition
- Automatic ash cleaning from the burn plate and heat exchanger tubes. The ash collection bin is typically emptied every 3-8 weeks depending on the fuel quality.
- Lambda probe measures oxygen levels in the exhaust and adjusts airflow and fuel feed rates to ensure optimal combustion efficiency and lowest emissions.
- Basic operation can be remotely monitored and controlled through a PC Modem

Typical Boilers Feature Cont.

High-Efficiency Compact Combustion Chamber and Heat Exchanger [18]:

- In the primary zone, air is supplied to gasify the fuel.
- In the secondary and tertiary combustion zones, air is tangentially delivered to create intense turbulence and achieve complete combustion of the fuel.
- The large heat exchanger surface area with turbulators ensure optimal heat transfer. (85-90% efficiency)

Multiple Safety Interlocks [18]:

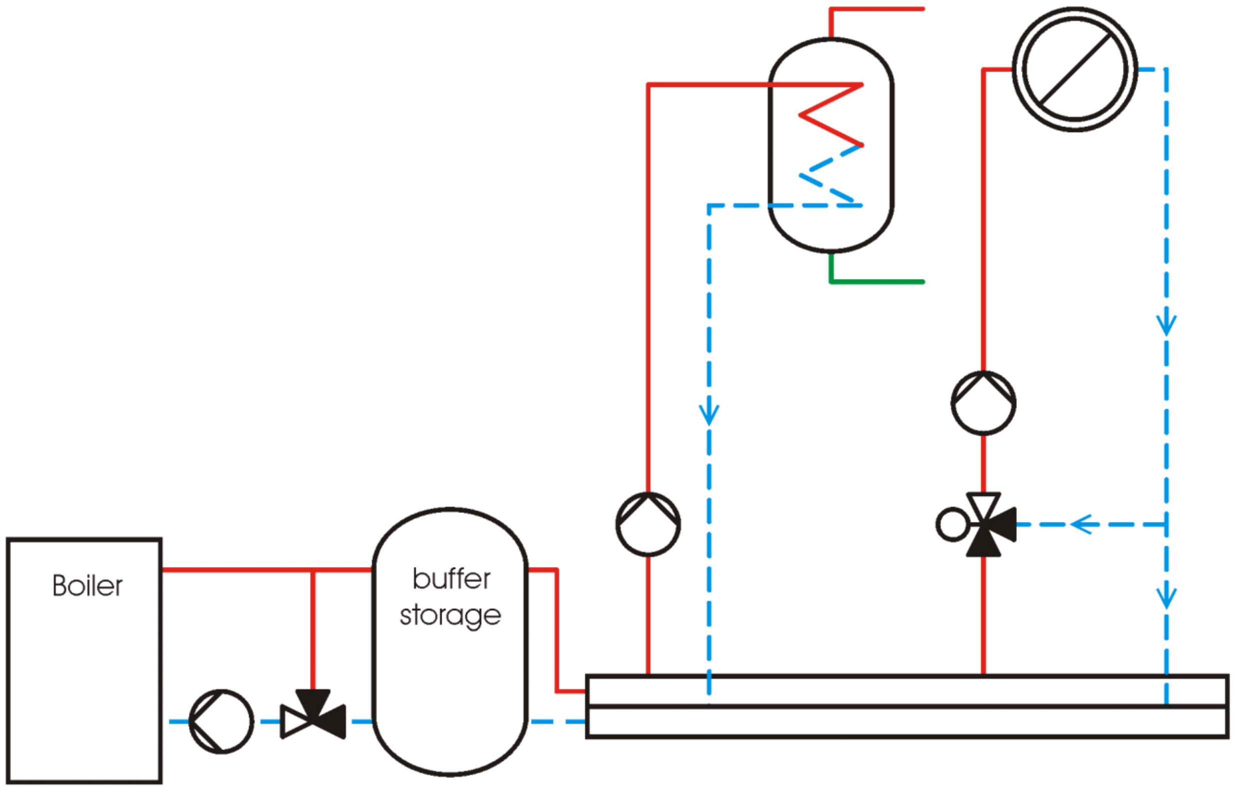
- Automatic shut down and extinguishing if unsafe conditions are identified in the boiler or the fuel storage chamber.

Heat Storage

Buffer Heat Store: It is a recommendation that a buffer or accumulator tank be incorporated as part of domestic wood pellet / chip boiler system installations where appropriate.

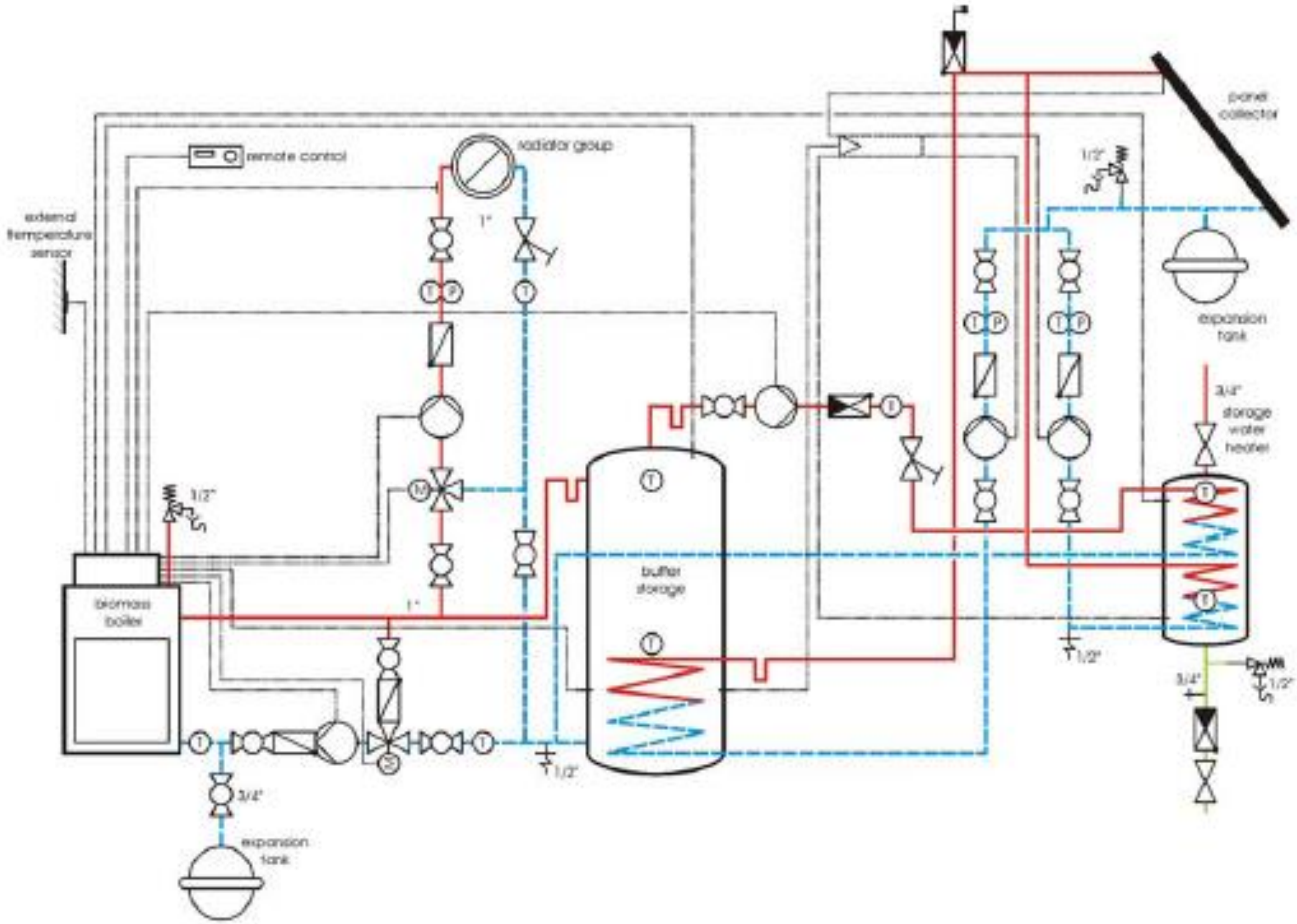
- A buffer or accumulator cylinder in a domestic biomass heating installation is a primary heat storage/distribution cylinder, which is heated by the boiler to a set temperature and can store the resulting high temperature water for long system standstill periods, until heating or hot water is required.
- A buffer / accumulator reduces the on/off cycling of wood boilers by "smoothing" the heat output to the dwelling.
- A buffer / accumulator also compensates for the slower changes in heat output from pellet and chip boilers as apposed to the more immediate effect oil or gas boilers have on heat output.

Heat Storage Cont.



buffer accumulator in serial connection [7]

Heat Storage Cont.



Example shows how a biomass and solar thermal installation are integrated with a buffer accumulator [7]

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